Hubble Space Telescope Observations of BL Lacertae Environments ⋆

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Abstract

We analyze images of BL Lacertae objects obtained with the *Hubble Space Telescope* WFPC2 and the F814W filter. The nine objects cover a redshift range of 0.19 to 0.997. The relatively deep images are sufficient to detect galaxies at least one magnitude below M_I^* (–21.4) and in most cases to three magnitudes below M^*. Galaxy enhancement over the average background is found around four out of the nine objects. Results for some cases are confirmed by ground-based imaging. In the other cases, the redshifts of the target BL Lac objects may be incorrect or they are truly isolated. These findings reinforce the idea that on average, BL Lac objects are found in regions of above average galaxy density. However, isolated objects apparently can host BL Lac nuclei too, a result that has implications for the processes that trigger/fuel the nuclear activity.

1 Introduction

BL Lacertae objects (BL Lacs) are an extreme form of active galactic nuclei (AGN) which exhibit rapid flux variability at all frequency, high polarization, and weak or non-existent spectral features. Along with their cousins, the Flat-Spectrum Radio Quasars, they form the blazar class of AGN. The model which

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best describes blazars is one in which a jet of relativistic material is beamed directly at us (Blandford & Rees 1978).

Although among the rarest types of AGN, BL Lacs are particularly important precisely because we can look into their jets. In this way, we can see the site of energy production which is presumably close to the central engine, or black hole. Thus, by studying these enigmatic objects we can better understand the central black hole in all other AGN.

One way of studying these objects, which is independent of any assumptions made about the nuclear regions and energy production, is by their environments. There is growing consensus that BL Lacs are found on average in poor clusters of galaxies (Falomo et al. 1993, Falomo et al. 1995, Stickel et al. 1993, Pesce et al. 1994, Pesce et al. 1995, Smith et al. 1995, Wurtz et al. 1997). However, some individual objects (e.g. PKS 0548–322) are found in rich clusters (Falomo et al. 1995).

Work has progressed on the kilo-parsec-scale environments, or host galaxies of BL Lacs as well. BL Lacs are found in giant elliptical galaxies with $-21.5 \lesssim M_V \lesssim -24.5$ mag (Abraham et al. 1991, Falomo 1996, Wurtz et al. 1996, Falomo et al. 1997, Urry et al. 1999). Some individual objects were thought to be hosted by spiral galaxies, but high resolution observations have shown them to be ellipticals (Urry et al. 1999).

High resolution images of the host galaxies of six radio-selected BL Lac objects observed with the *Hubble Space Telescope (HST)* have been presented in Falomo et al. (1997) and Urry et al. (1999). These are relatively deep WFPC2 images from cycle 5. In addition, we are currently analyzing the host galaxies and extended environments of more than 100 BL Lac objects at redshifts 0.03 - 1 observed by HST as part of a snapshot project (Pesce et al. 2000, in preparation; Scarpa et al. 2000 in preparation; Urry et al. 2000, in preparation). The combined dataset will allow a thorough investigation of BL Lac environmental properties over a large redshift range.

In this paper we present the analysis of the extended environments of six radio selected objects from our HST cycle 5 GO project (PI URRY). To this sample we have added three X-ray selected objects obtained from the HST archive and observed during cycle 5 (PI JANNUZI). We assume $H_0 = 50$ km s^{-1} Mpc$^-1$ and $q_0 = 0.5$.

Table 1
BL Lac Target Objects.

Object	z	Exp (sec)	$m_{\rm I}^{*\#}$
0814+425	0.258	475	19.7
0828+493	0.548	2060	21.4
1221+249	0.218	1900	19.3
1308+326	0.997	1800	22.8
1407+599	0.495	4080	21.2
1538+149	0.605	1670	21.6
1823+568	0.664	2120	21.9
2143+070	0.237	850	19.5
2254+074	0.190	1480	19.0

[#] Apparent magnitude of a typical galaxy, assuming $M_{\rm I}^* = -21.4$. No K-correction has been applied.

2 Data Reduction & Analysis

The objects were observed with the WFPC2 and the F814W (I-band) filter, the BL Lac was centered in PC camera. Exposure times varied and were approximately 10 min to 1.5 hours (see Table 1). More details about the reduction and analysis of these fields can be found in Urry et al. (1999).

We used the FOCAS software, in IRAF, to detect and classify all objects on an image and produce a catalog (Figure 1). For the central BL Lac, the Point Spread Function (PSF) was created with Tiny Tim (Hasan & Burrows 1995); each object is classified as 'Star' or 'Galaxy' based on an automatic comparison of its profile to a standard PSF profile. In these images, we detect objects down to a "completeness limit" of $m = 24$. Objects fainter than the completeness limit are not considered in the analysis of the images.

The automatic identifications from FOCAS were checked with simulated images consisting of stars, galaxies, and noise. FOCAS detected and correctly classified all objects above the completeness limit and 90% of objects below the limit. As a further check, the galaxy density on each image was compared to the average background density for the F814W filter from Casertano (1997, priv com).

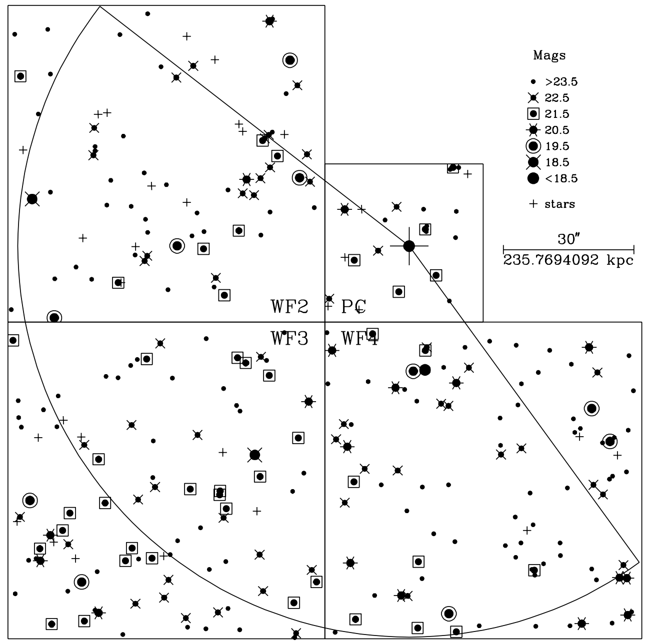

Fig. 1. A map of the region around 1823+568, as seen by HST. The Planetary Camera is labeled as PC while the three wide field chips are WF2, WF3, and WF4. The object is marked by the large cross centered in the PC and the other symbols are explained in the key. For this object, $z = 0.664$ and the PC is ∼280 kpc square, while the maximum complete radius sampled (the straight lines and arc) is ∼0.7 Mpc.

3 Results

To avoid background contamination, we only count galaxies with $m_I \leq m_I^* + 1$ where $M_I^* = -21.4$. The PC images subtend 0.3 arcmin^2 while the WF chips subtend 1.5 arcmin^2 giving a maximum radial extent from our BL Lacs of 0.4 - 0.8 Mpc. Most BL Lac clusters are found within 0.5 Mpc of object (Pesce et al. 1994, Pesce et al. 1995). However, because of the WFPC2 geometry, we only observe ∼1/2 of the volume surrounding the BL Lac.

We checked our procedures by analyzing an archival image of the rich cluster Abell 2390 (richness class 1, $z = 0.231$, exposure = 2100 s). On this image, we detected a significant (factor 9-20) overdensity of galaxies.

For our objects, we **detect enhancements (factor 2-4) above background in four cases:** 1407+599, 1538+149, 1823+568, 2143+070. A modest enhancement is found around 2254+074, but this object has the lowest redshift so we are observing only a small part of the potential cluster volume.

No enhancements are found for 0814+425, 0828+493, 1221+249, 1308+326. Given our completeness limit, and assuming correct redshifts, we *should* detect any cluster present (if the cluster is approximately symmetric). **These objects appear to be truly isolated.**

4 Conclusions

We have analyzed the extended environments of nine BL Lac objects observed with the HST WFPC2 in the F814W filter. The long exposures provide deep ($m \sim 24$ mag) images. We find significant enhancement of galaxy density around four of the nine BL Lac objects (1407+599, 1538+149, 1823+568, 2143+070). In some cases (1407+599, 1823+568) the enhancement is extreme, with dozens of galaxies within ∼150 kpc of the BL Lac object.

The remaining five fields show no indication of excess galaxy counts. In fact, some fields are slightly below the average background galaxy density, although in general the galaxy density is consistent with the background. These objects are either truly isolated, their clusters are unusually asymmetric (and strangely all out of the field of view), or the redshifts are incorrect. Of these three explanations, the first is most likely. Thus, some BL Lac objects appear to be in regions of significantly enhanced galaxy density, while others seem to be completely isolated. This result is not surprising given that BL Lac hosts appear to be otherwise normal giant elliptical galaxies. Such galaxies are found in all types of environments - from rich clusters to isolated regions of space. Nonetheless if galaxy interactions play an important role in the AGN activity, future work needs to address this point. Our sample is too small to determine differences between X-ray and radio selected objects, a point to be addressed in our analysis of the larger HST snapshot survey.

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